# CTCN assistance in Thailand

## Strengthening Bangkok's Early Warning System to respond to climate induced flooding

## Deliverable 3 (Activity 1.2.2) Updated model and performance documentation

Draft final 1st February 2017

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# Contents

# 1 Introduction

An urban flood model for the Sukhumvit area in Bangkok was first built in 2002 (Boonya-aroonnet et al., 2002), and had been continually developed and used for various flood risk analysis and real-time flood forecasting studies (see Chingnawan, 2003; Hung et al., 2005; Chitwatkulsiri, 2015). It is an integrated 1D/2D flood model, dynamically simulating overland surface flows as well as subsurface drainage network flows, with GIS functionalities for result visualisation. The 1D model component describes the major drainage elements in the area, including the open canals (*klongs*), pumps, drainage pipes, manholes, and inlets, while the 2D surface model simulates the urban terrain.

An objective in the technical assistance project is to update and reconfigure the existing Sukhumvit model to suit real-time flood forecasting applications. The flood model should reflect recent changes in city features and ensure proper representation of the area's drainage characteristics. In addition, optimum model performance, with respect to computational speed and accuracy, is needed in real-time forecasting applications. Real-time forecasting involves the use of current and short-term future predicted driver and system conditions to determine if, when and where flooding would occur. Requirements for offline flood analysis focus more on high-resolution modelling of terrain and drainage networks, and less on computational time, and very detailed integrated (i.e. 1D/2D) models covering large areas are computationally heavy and prone to run slower than real-time, leading to their limited use in operational early warning applications.

The efficiency of 2D models is a major challenge to flood modellers. Model efficiency depends on the chosen time steps, size of model area, the efficiency of numerical algorithms and the use of multi-processing, among others. Reducing model accuracy affords faster computations, but potentially at the expense of detail level and correctness.

Thus, in the flood model update, the aim was to achieve a balance between model speed and accuracy. Data on major structural changes in the drainage system as well as the urban surface (i.e. streets, buildings) were collected and used in reconfiguring the model. In addition, model speed-up techniques were applied to improve model performance for real-time flood forecasting. In summary, update of the Sukhumvit flood model involved:

- Model checking and validation. Checking of the existing Sukhumvit flood model against recent available drainage system data, such as pump station characteristics, pump operation, and terrain elevations.
- Model optimisation. Reconfiguration of the flood model according to recent drainage system data, and application of speed-up techniques to optimise the model for flood forecasting.

# 2 Sukhumvit Flood Model

The flood model covers the area of Sukhumvit in Bangkok (Figure 1). It is a highly urbanised commercial area around 24 $km^2$ in size and with a population density of around 8 400 persons/$km^2$.

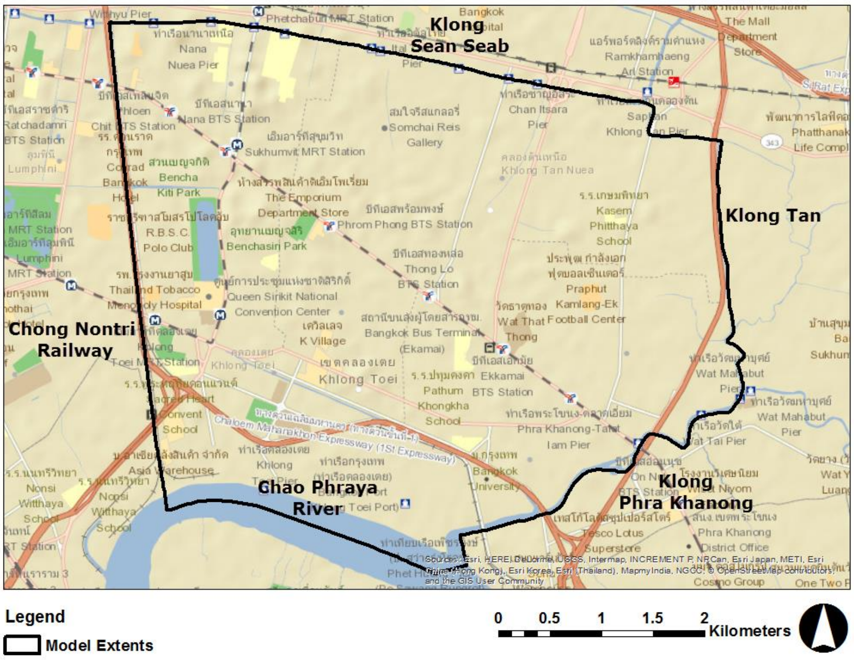


Figure 1 The Sukhumvit flood model extent showing the locations of various drainage boundaries.

The terrain is relatively flat and sits low at an elevation of around 0.4-1 m above mean sea level (MSL). Thus, stormwater drainage out of the area relies heavily on pumps as terrain characteristics make gravity drainage into canals difficult.

The existing 1D/2D flood model, obtained from the study by Chitwatkulsiri (2015), is plotted in Figure 2, showing the 1D drainage network model overlaying the 2D surface model grid. This type of coupled modelling method uses a 2D surface model dynamically linked to a 1D network model to simulate flooding. Flows over the terrain surface are simulated with the 2D model, which calculates water levels and flows overland, while the 1D model represents the drainage network, and simulates flows and water levels in the network (Henonin et al., 2013). The two systems are linked at structures where flow exchange between the two systems may occur (Figure 3).

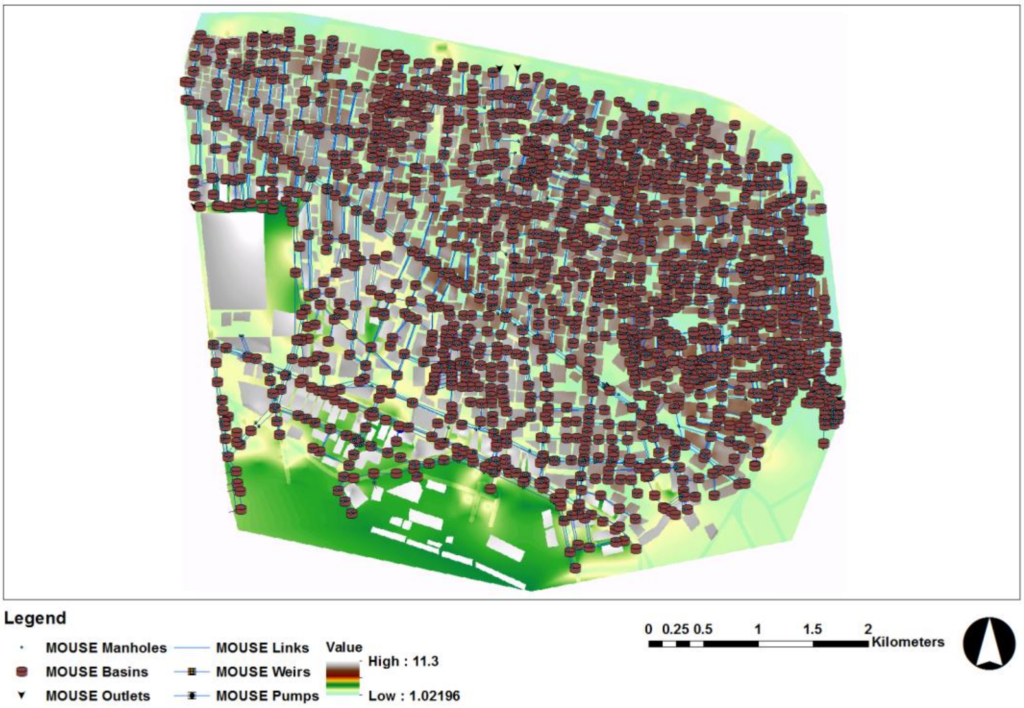


Figure 2 Plot of the existing Sukhumvit 1D/2D flood model showing the 1D network model elements and the 2D urban surface model.

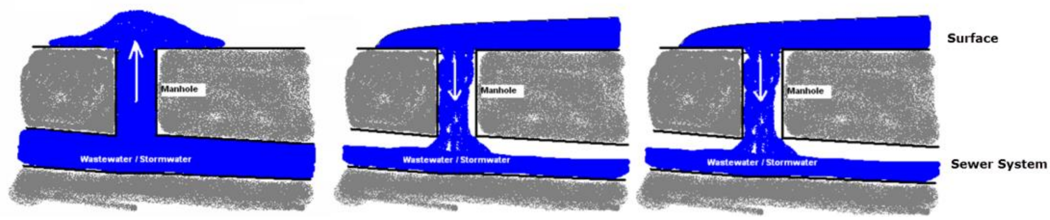


Figure 3 Dynamic flow exchange mechanisms afforded by the integrated 1D/2D flood modelling method. (Source: DHI, 2015c)

The 1D model component simulates the sewer network, comprised mainly of pipes, open channels, manholes, pumps and basins. The study area had been divided into 2 000 sub-catchments, which discharge a mixture of stormwater and wastewater into the drainage network. The model is made up of around 3 500 nodes representing manholes, stormwater inlets, and basins, and 3 800 links modelling 430 km of underground pipes and channels in the area.

The 2D surface model component uses a 10 x 10 m Cartesian computational grid to simulate the urban topography in the study area (Figure 4). Terrain levels had been interpolated from 4 600 point-elevation data obtained from BMA (Figure 5). The presence of buildings was also considered in the 2D model to reflect the influence of these structures over surface flows. Building shapes were manually digitised from an aerial photo of the area, and terrain levels over the buildings artificially raised so they may serve as obstructions to surface flows in the flood simulations (Figure 4 and Figure 6). Moreover, roads were also reflected in the topography grid by lowering terrain levels over these areas by 25 cm (i.e. assumed curb levels) (Figure 4).

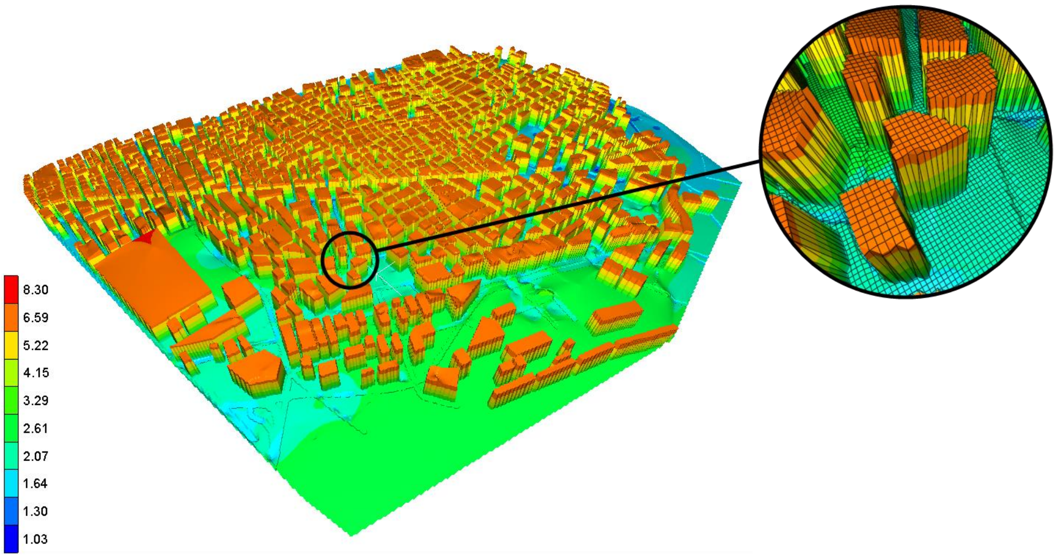


Figure 4 A 10 x 10 m computational grid simulating the urban terrain is used in the 2D surface flow model. It reflects road alignments and the presence of buildings in the study area.

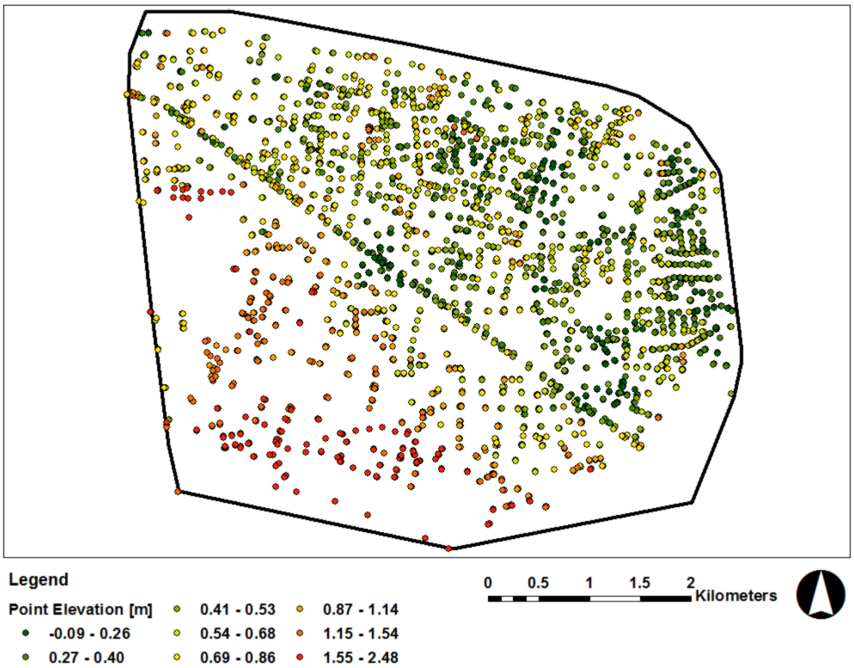


Figure 5 Plot of the 4 626 point elevation data used to interpolate the topographical surface in the study area.

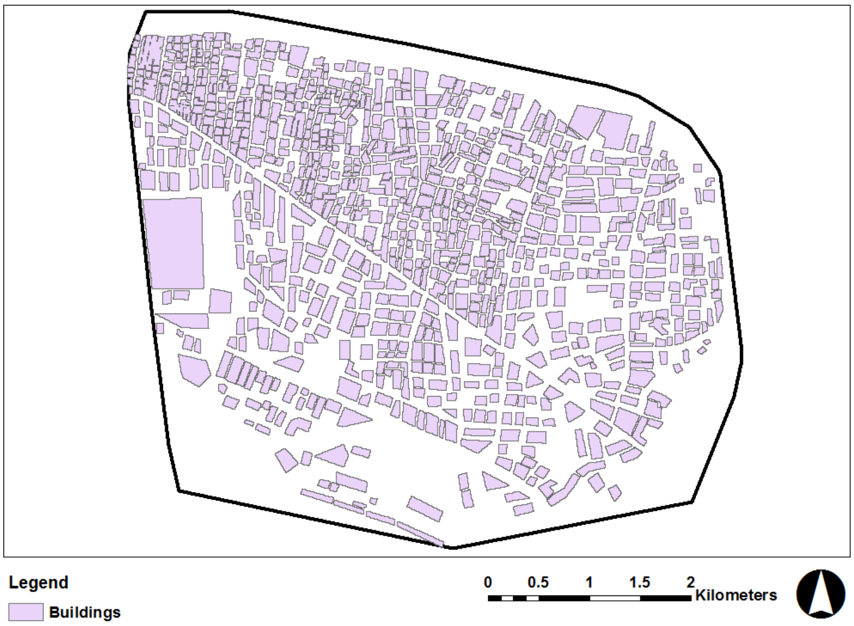


Figure 6 Plot of the 910 building shapes manually digitised based on an aerial photo of the study area.

## 2.1 Model Checking and Validation

### 2.1.1 Model Configuration

Inspection of the existing flood model revealed that surface storage over streets had been considered twice – in the 1D model as well as the 2D model. As described in the previous section, the street networks were represented in the 2D topography grid through lowering of the terrain over these areas. However, streets had also been represented in the 1D model through use of open channels (i.e. representing streets) and artificial basins representing surface storages along the streets and beyond curb levels. Thus, the large number of “basins” in the model is observed, as well as multiple parallel link segments along the streets (Figure 7).

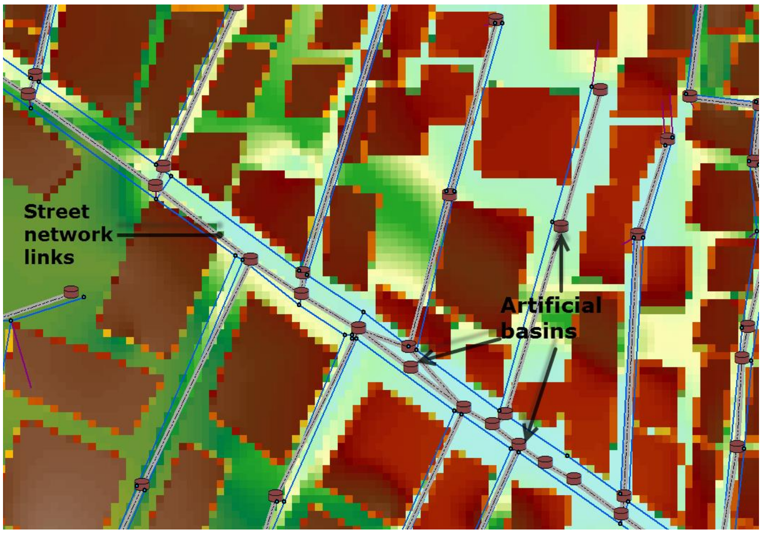


Figure 7 The street network had been represented in the 1D model using artificial basins representing street and overland storages beyond curb levels.

This is a type of flood modelling method (i.e. 1D/1D) based solely on 1D computations (Figure 8). In this method, flooding is simulated as overflow from the underground sewers onto the streets, which are modelled by a second 1D layer representing the street network (Mark et al., 2004, Henonin et al., 2013). The two layers are dynamically linked, and surface flooding beyond curb levels are represented by area-capacity curves derived from the topography. In the case of the Sukhumvit model, the artificial basins represent the area-capacity curves for storage. This is a completely valid type of flood modelling method. However, for Sukhumvit, 1D/2D modelling is used, and as the street- and surface-storage capacities are already reflected in the 2D model, the 1D model should no longer represent these components to avoid double consideration of storages, which will affect surface flood volumes and extents.

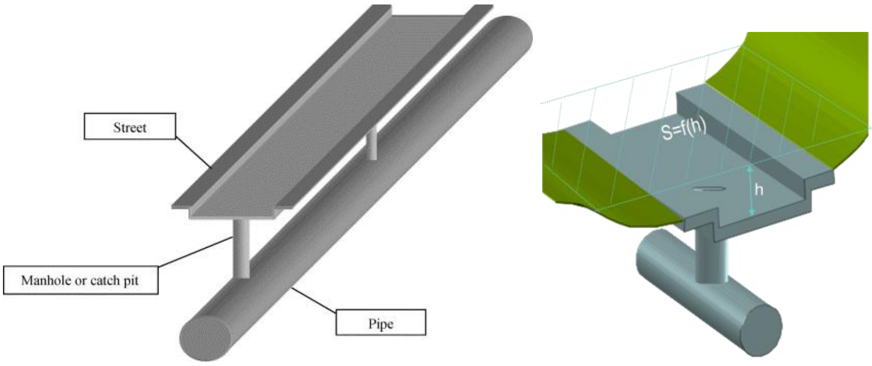


Figure 8 Schematic diagrams illustrating the 1D/1D pluvial flood modelling method, which employs a double layer of the sewer and street network to simulate urban flooding (Mark et al., 2004).

Thus, the artificial basins and links representing the overland street network were removed from the 1D drainage network model. In the updated 1D/2D flood model, stormwater and wastewater drain into the underground sewers (Figure 9). This effectively reduced the number of nodes in the model from 3 500 to 2 100, and the links from 3 800 to 2 400.

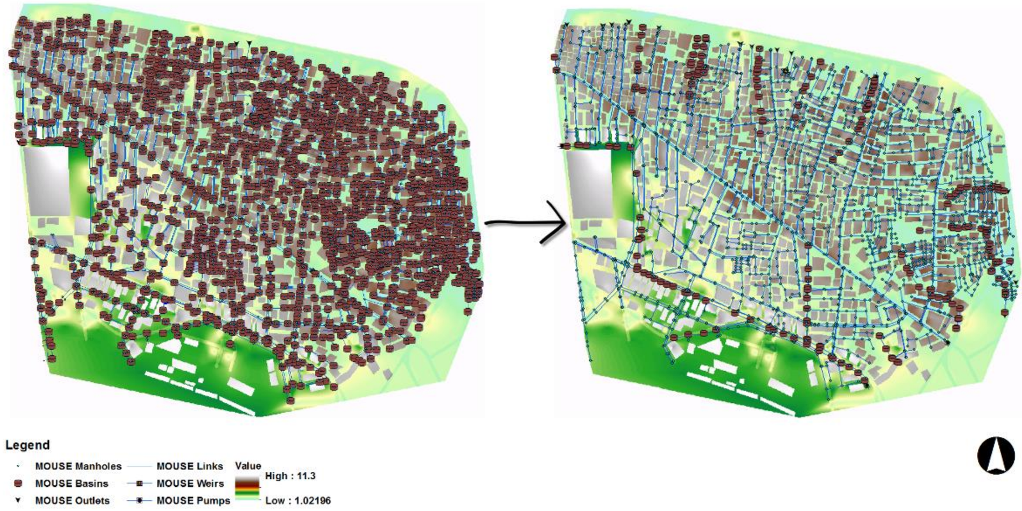


Figure 9 The street network layer represented by artificial basins and links (left) were removed in the updated 1D network model (right). Note the lower number of basins compared to the model shown in Figure 2.

The sewers are dynamically linked to the 2D surface flow model, and water emerges on the surface as flooding when the underground network is overwhelmed. Flooding propagates according to the terrain, and water could enter the sewers once space is available in the underground network. In the updated 1D/2D flood model, storage along streets and over the terrain is only represented in the 2D model component.

### 2.1.2 Projection System

The projection system of the flood model was corrected to consistently georeference it as other GIS data at BMA. It was re-projected to standard UTM coordinates for Bangkok (WGS 1984 UTM Zone 47N). Moreover, this allowed the overlay of the flood model and results with publicly available online satellite images and street maps.

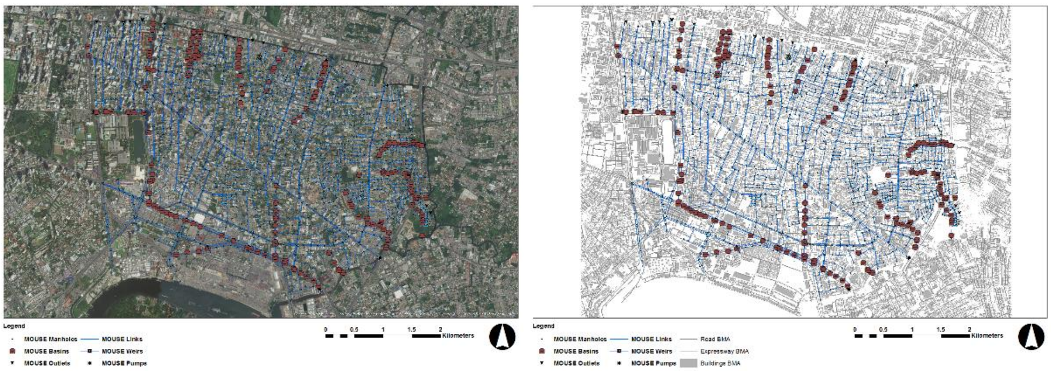

Figure 10 The Sukhumvit flood model was re-projected to standard UTM coordinates allowing overlay with open street and orthophoto maps (left) and GIS data at BMA (right).

### 2.1.3 DTM Data

New DTM data was obtained for the Sukhumvit area. It has a grid resolution of 2 m and reflects the lowered levels of streets and open channels in the area (Figure 11). This new dataset was used to re-interpolate the topography for the 2D model together with previously available spot-elevation data (see Figure 5).

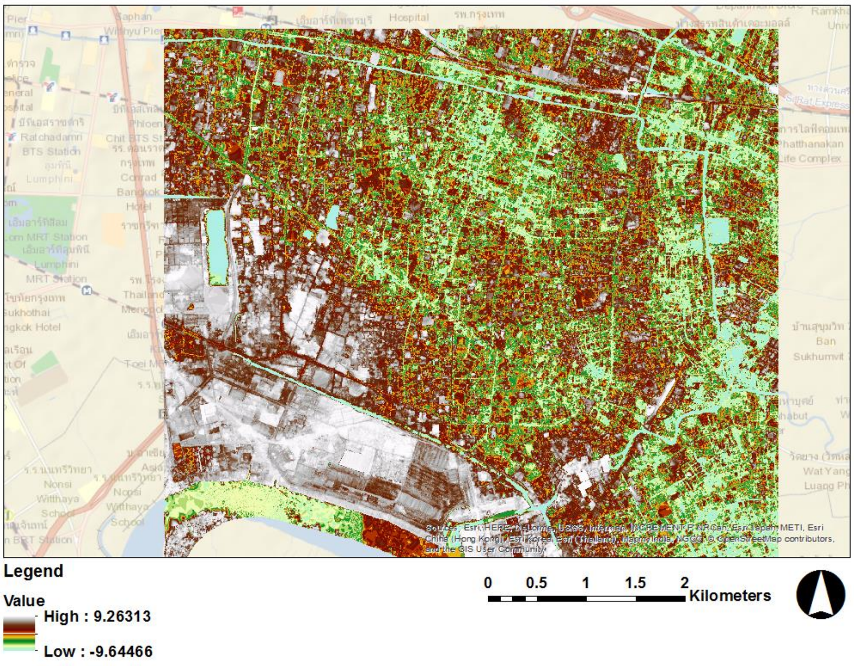


Figure 11 New DTM data for the Sukhumvit area used to update the 2D model.

### 2.1.4 GIS Data

The representation of buildings in the 2D model grid is important in flood simulation as it affects flood propagation and eventual extents over the urban terrain. Close inspection of the original digitised building shapes (Figure 6) showed their imprecise description of buildings, identifying the need to improve building shape description (Figure 12). Building shape data was obtained from BMA, and were used to reflect buildings in the updated 2D model grid.

Figure 12 Old digitised building shapes (left) imprecise in describing buildings compared to the new building shape data (right) obtained from BMA.

### 2.1.5 Pump Data

Because of the flat and low-lying terrain in the study area, the primary way with which stormwater is evacuated from the catchment is through pumps. Thus, it is important that pump installations in the area are accurately described in the model.

Most of the pump data in the existing model were updated with respect to:

- Pump capacities
- Wet-well set point levels

### Start and Stop Levels

Upon checking, original pump start and stop levels for several pumps were found questionable, as start levels were higher or equal to sump ground levels. These pumps include:

Table 1 Pumps with faulty pump data in the original 1D model

| MUID | Start Level [m] | New Start Level [m] | Stop Level [m] | Sump Ground Level [m] |
|---|---|---|---|---|
| G1201p1 | 1.00 | 0.50 | 0.00 | 1.00 |
| PU_B2/1p1 | 0.40 | -0.20 | -0.30 | 0.30 |
| T1p1 | 0.80 | 0.44 | 0.35 | 0.54 |

Start levels were modified, if possible, to 50 cm below sump ground levels for the pumps listed above. For pump T1p1, this is reduced to 10 cm below sump ground level to avoid pump start level going below pump stop level (0.35 m).

### Pump Capacities

BMA (2017) has information on the total capacities at each pumping station in the Sukhumvit area (Figure 13). It was ensured that these stations were represented in the network model, and that pump capacities corresponded to current values.

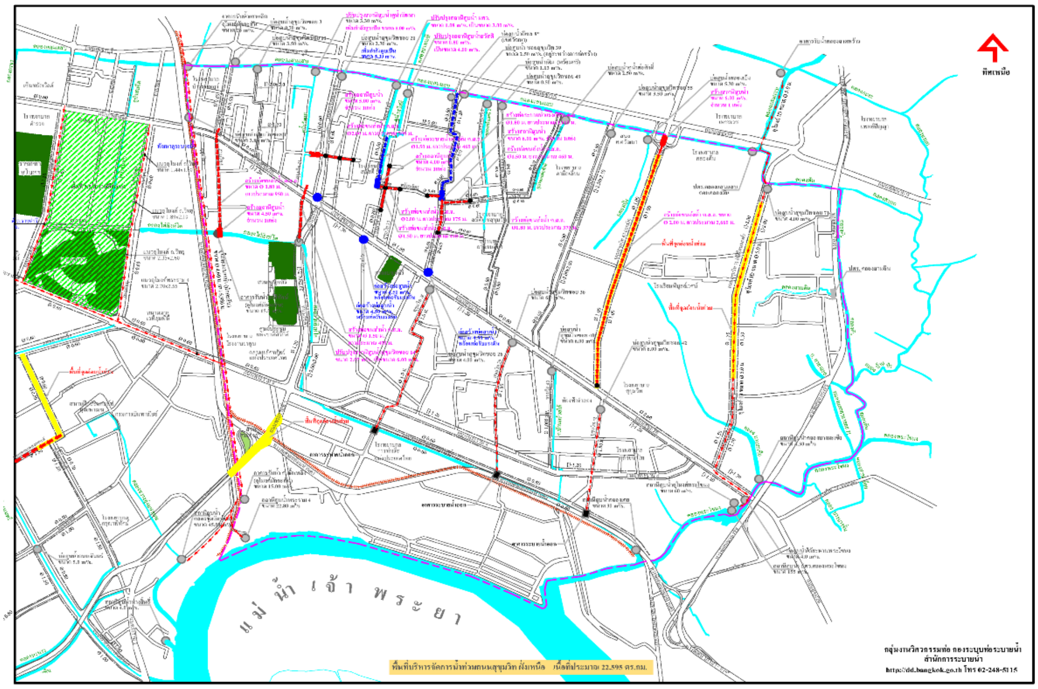

Figure 13 Existing and planned pump capacities for various pump stations in the Sukhumvit area (Source: BMA, 2017)

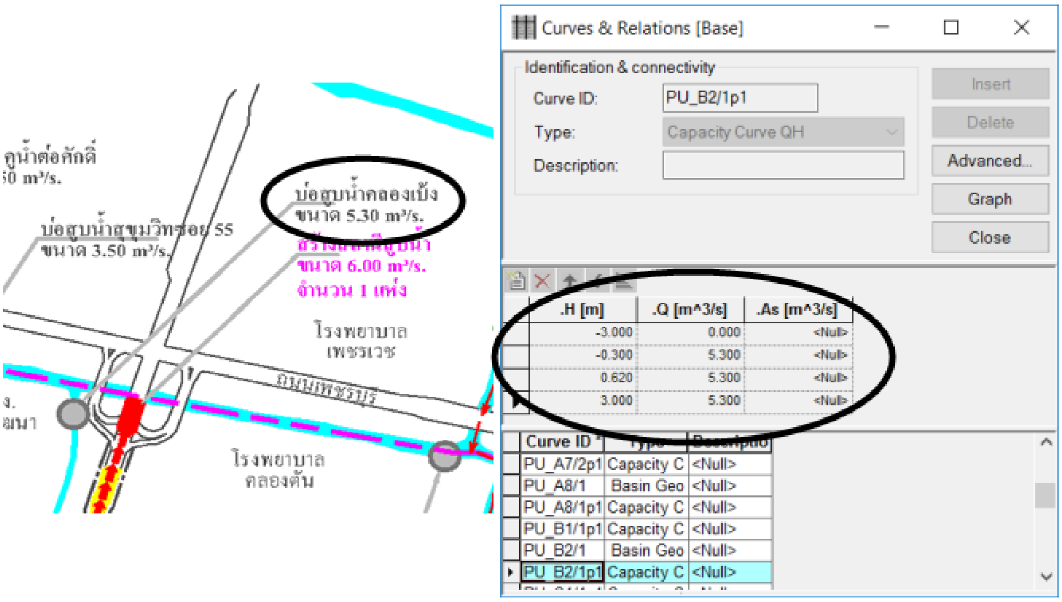


Figure 14 Update of pump capacities in the model based on BMA data (BMA, 2017).

## Pump Set Points

Data on pump operation was also obtain from BMA. Pumps in the area are apparently operated manually to maintain wet well/sump water levels (i.e. control levels), which vary according to the following weather conditions:

- Plan A: Rain expected
- Plan B: Normal conditions
- Plan C: Pollution flushing

For example, at one pumping station discharging to Klong Sean Seab near Asok Pier (WTN04/1p1), a water level of -0.5 m is maintained at the station on normal (i.e. dry) conditions (Figure 15). This target is lowered to -1.0 m when rain is expected to make space in the sewer network for the oncoming stormwater runoff. In the model, these control levels were specified as “Wet well set points”, and during model computations, pump operation and capacities are dynamically regulated to maintain these specified control levels at the source node/sump.


Figure 15 Control level data at a pumping station near Asok Pier.

For the operational flood model, control levels for rainfall conditions (i.e. Plan A) are maintained, as the model’s primary purpose is for early warning of potential flooding (during rain) in the study area.

Control level data was not available for all pumping stations. Thus, for rainfall conditions (Plan A), the following were assumed:

- Set points are taken from BMA data (BMA, 2017), if available
- Pump set points shall not go below 1 m above sump inverts (to, in principle, avoid pump damage)
- Control set points shall not go above dry weather (Plan B) set points

For dry conditions (i.e. Plan B):

- Set points are taken from BMA data (BMA, 2017), if available
- Control set points shall, as much as possible, be equal to the specified start level for pumps in the original model
- Pump set points shall not go below 1 m above sump inverts (to, in principle, avoid pump damage)
- Control levels at pump stations without control level data were assumed at 1.3 m below sump ground levels.

### 2.1.6 Dry Weather Flow

In the original model, dry weather inflows into the sewer network comprised:

- 1 $m^3$/PE/day population wastewater discharge following a diurnal pattern. (Kept in the updated model)
- 10 $m^3$/PE/day constant base flow (i.e. infiltration). (Removed in the updated model)

#### Wastewater Discharge

The wastewater discharge amount was compared against water consumption data for the period 2010-2015 obtained from BMA (Figure 16), which indicate that on average, water consumption in the study area totals around 55 MCM/yr. The diurnal wastewater discharge of 1 $m^3$/PE/day, with 153 826 people, amounts to 56 MCM/yr, which is comparable to the recorded water consumption.

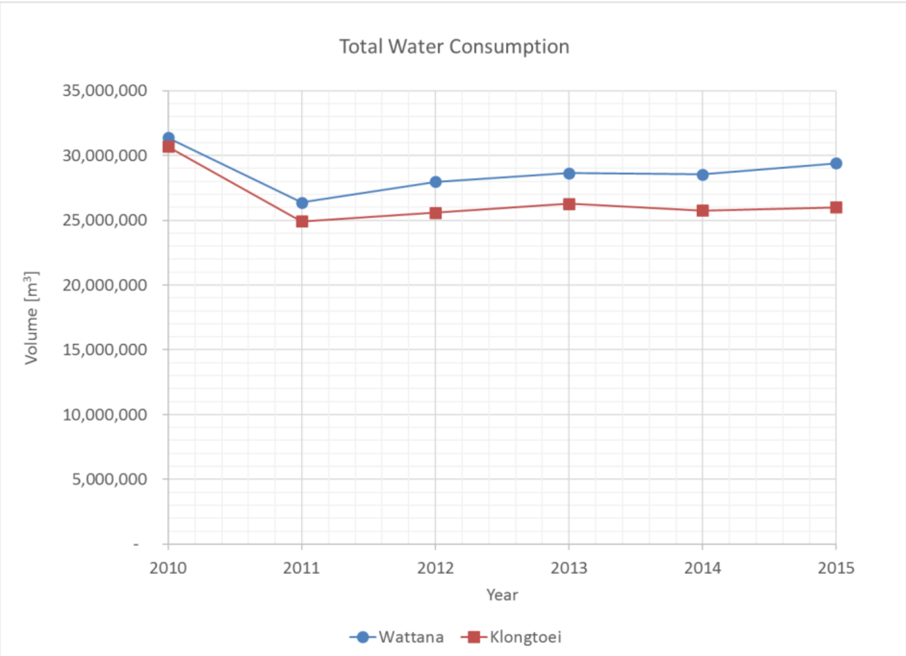


Figure 16 Data obtained from BMA on yearly total water consumption for the period 2010-2015 in the districts of Wattana and Klongtoei (comprising the study area).

## Backflow and Infiltration

The modelling of infiltration or backflow into the system was modified such that instead of unrealistic application of 10 $m^3$/PE/day of baseflow into the network, water level boundaries were applied at the outlets of the sewer network to simulate backflows during high water level conditions (i.e. in the *klongs* and river). Estimates of backflow conditions, which are shown in Figure 17, were derived based on discussions with BMA.


Figure 17 Backflow locations, as discussed with BMA.

To model backflows that start at certain levels at some of the outlets (see Figure 17), weir elements were used to represent outlet connections to the network (Figure 18). This is to ensure that, in the calculations, inflows to the network only occur when outlet water levels go beyond backflow start levels. In the model setup, crest levels for these weir connections were set at the levels around which backwater inflows start.

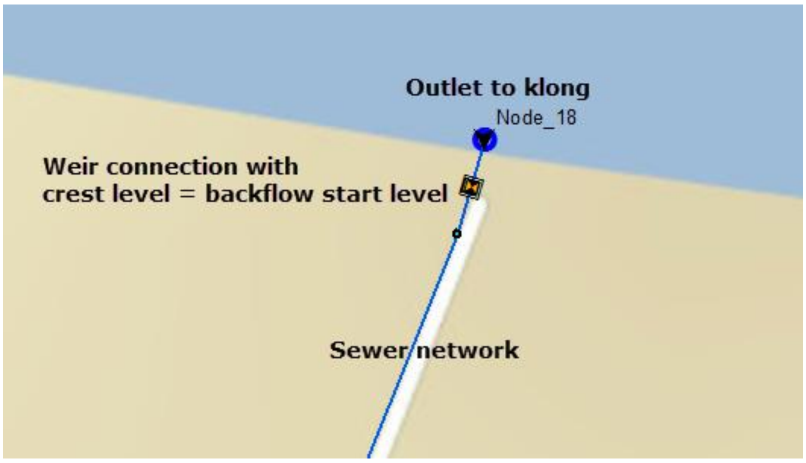


Figure 18 Weir connections were used at some of the outlets to control the backflows into the network according to water levels.

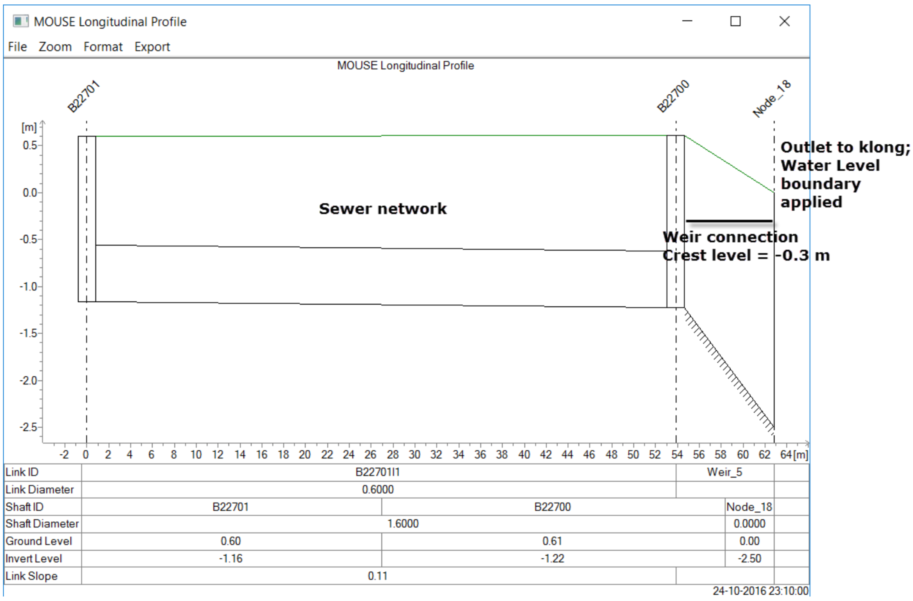


Figure 19 Profile plot of the network section in Figure 18 showing the schematisation of outlet connections to model backflows.

Pump discharge data for three pumping stations during the dry weather period 1-18 February 2017 were obtained from BMA (Figure 20 and Table 2), and were used to calibrate wet well set points for the corresponding pumps in the network model.

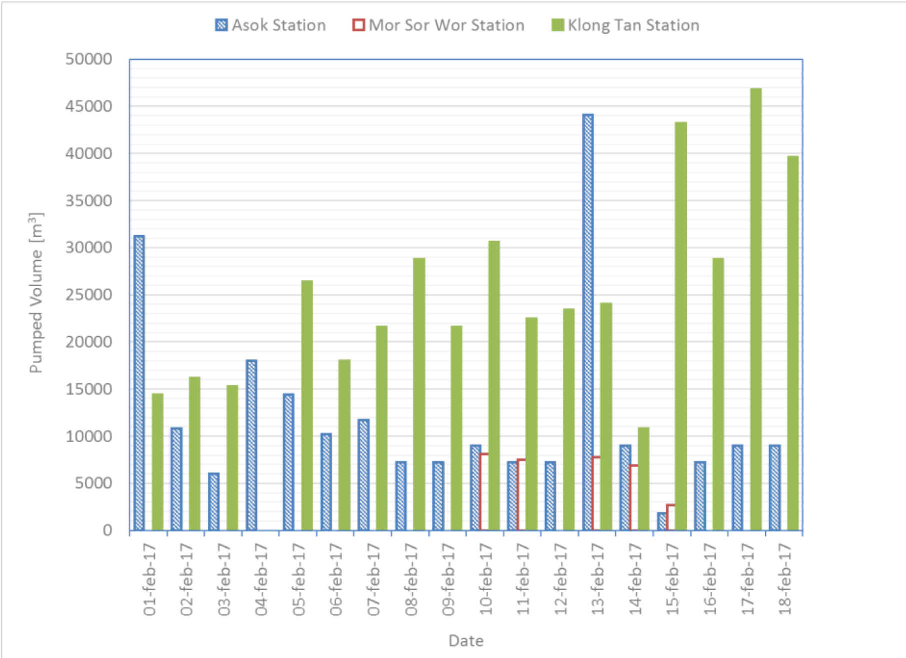


Figure 20 Daily pumped volume data at three pumping stations during the (dry) period 1-18 February 2017.

Table 2 Pump stations for which discharge data during the period 1-18 February 2017 were obtained from BMA.

| Station | Longitude, Latitude | Pump ID | Observed Ave. Pump Discharge [$m^3$/d] | Simulated Pump Discharge [$m^3$/d] | Dry weather Wet Well Set Point [m] |
|---|---|---|---|---|---|
| Asok | 13.747654, 100.563116 | PU_A3/1p1 | 12 233 | 12 232 | -0.43 |
| Mor Sor Wor | 13.746737, 100.567794 | PU_A5/1p1 | 6 600 | 6 753 | -1.30 |
| KlongTan | 13.740677, 100.598272 | PU_C1/1p1 | 24 800 | 23 431 | -0.76 |

By comparing simulated accumulated pump discharges over a dry weather period to average observed pump discharges (Table 2), set points were adjusted until total accumulated discharge volumes were similar. In addition, recorded water levels at Asok station during the dry weather period were available (Figure 22), and indicate that the adjusted wet sell set point at Asok pumping station (-0.43 m; see Table 2) well-approximates the average (-0.41 m) actual operational control level (ranging from -0.3 - -0.65 m; see Figure 22).

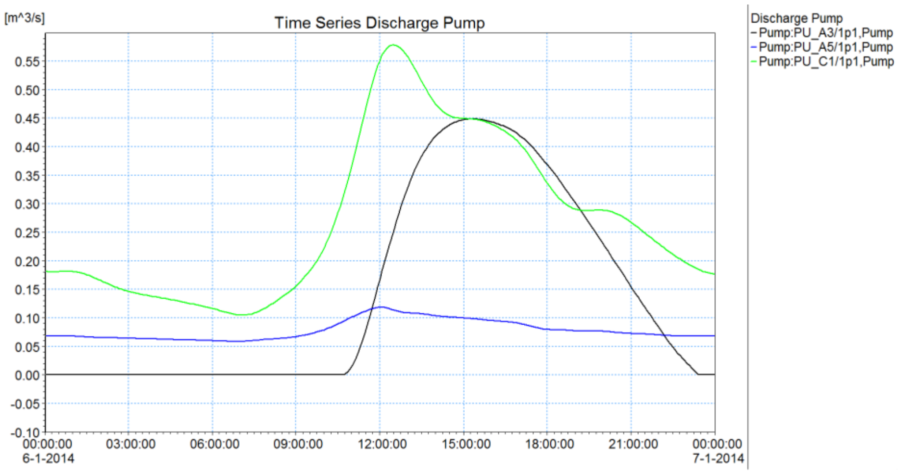


Figure 21 Simulated pump discharges for pumps PU_A3/1p1 (Asok), PU_A5/1p1 (Mor Sor Wor), and PU_C1/1p1 (Klong Tan) over a 1-day dry weather period. Accumulated volume values for each are shown in Table 2.

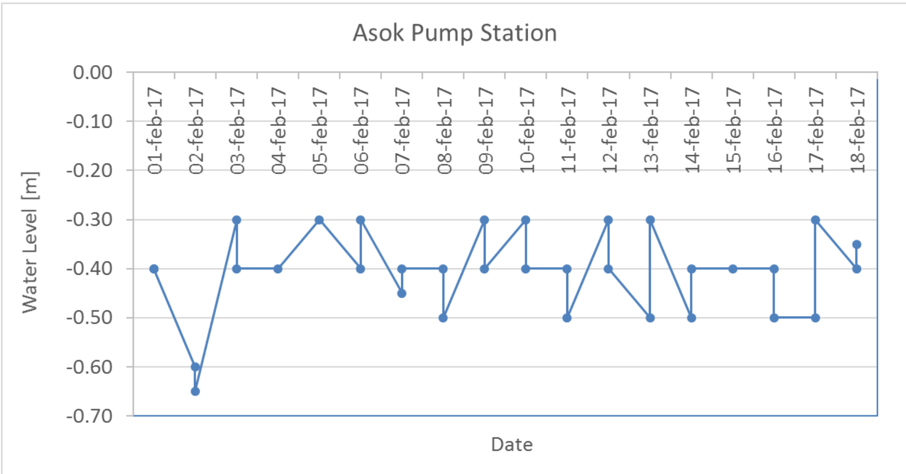


Figure 22 Recorded dry-weather control levels at Asok pumping station.

## 2.2 Model Optimisation

### 2.2.1 Model Extents

In general, the number of (active) computational points, and accordingly, computation time, varies proportionally with model extents. Thus, refining the model domain may afford savings in simulation times. Careful delineation of model extents considers the dominant processes involved, interest area for main stakeholders, area of influence of simulated phenomenon, and boundary locations. The Sukhumvit flood model is delimited by clear hydrological boundaries—i.e. the Chao Phraya River, the *klongs*, and the railway line. The 2D model extents were re-defined following these clear boundaries, as well as the coverage of the 1D network model (i.e. catchments and sewers) (Figure 23).

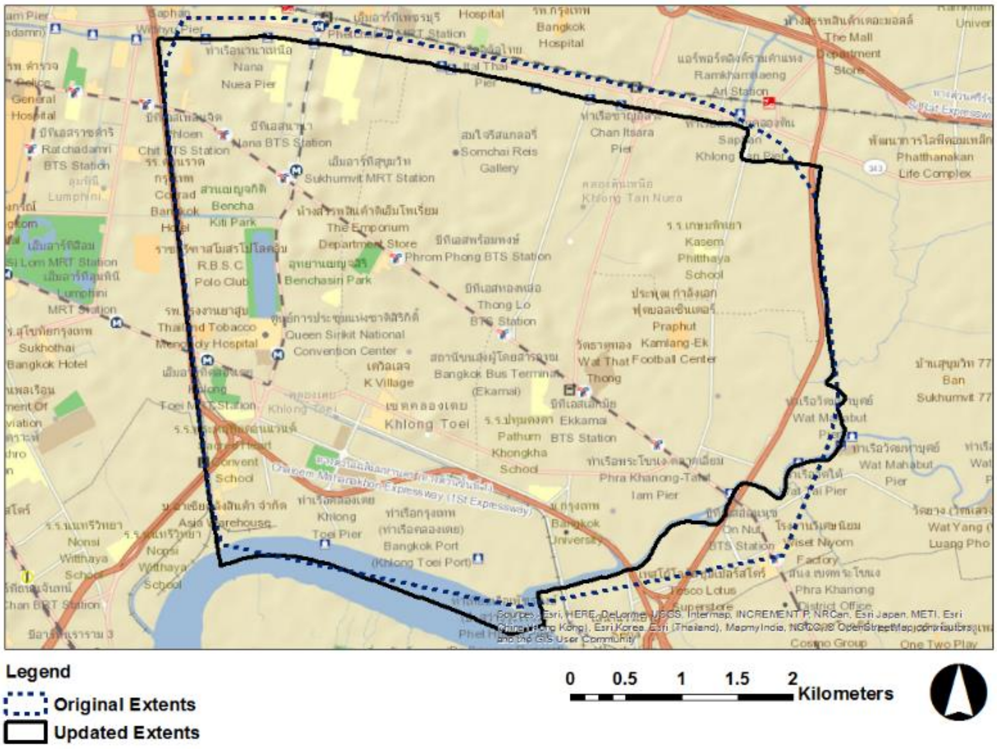


Figure 23 Modification of 1D/2D flood model extents.

### 2.2.2 2D Computational Grid

The existing (i.e. former) Sukhumvit flood model used a rigid-grid 2D model with a resolution of 10 m (i.e. 100 $m^2$ grid squares). This is too coarse for urban flood simulations, as streets in the study area can be at least 5 m wide. Thus, the existing 2D model grid warranted refinement. However, as was already the case with the coarse 10-m resolution, the best relative computational speed (i.e. simulation time/computation time) that could be achieved was only 2.4 (Chitwatkulsiri, 2015; see Table 3), which is insufficient for flood early warning purposes. Further refinement of the rigid computational grid would likely extend computation times, as the number of grid cells exponentially increase, and small computation time steps are required for model stability. Thus, application of a different model speed-up technique was needed.

Table 3 Computational speed of the former Sukhumvit 1D/2D flood forecast model. (Source: Chitwatkulsiri, 2015).

| Case | Total Rainfall Duration [min] | Model Run Time [min] | Relative Computational Speed |
|---|---|---|---|
| Case 1 | 5 | 5 | 1.0 |
| Case 2 | 10 | 7 | 1.4 |
| Case 3 | 15 | 10 | 1.5 |
| Case 4 | 20 | 13 | 1.5 |
| Case 5 | 30 | 17 | 1.8 |
| Case 6 | 40 | 17 | **2.4** |
| Case 7 | 50 | 22 | 2.3 |
| Case 8 | 60 | 26 | 2.3 |

To achieve faster simulations with the Sukhumvit flood model, the 2D computational grid was converted from a rigid grid to a flexible mesh (Figure 24). This affords shorter computation times without loss of model accuracy.

Mesh elements can resolve important surface features affecting overland flows, and can be more readily arranged to reflect complex flow paths in the model domain. Mesh element sizes may be varied in different zones within the domain depending on the dominant processes being analysed, the major overland flow paths, or the main area of interest. Spatial adjustment and distribution of differently sized elements in the domain enables optimisation of the number of computational points, wherein a low number of computational elements may be achieved while still ensuring accurate description of surface features.

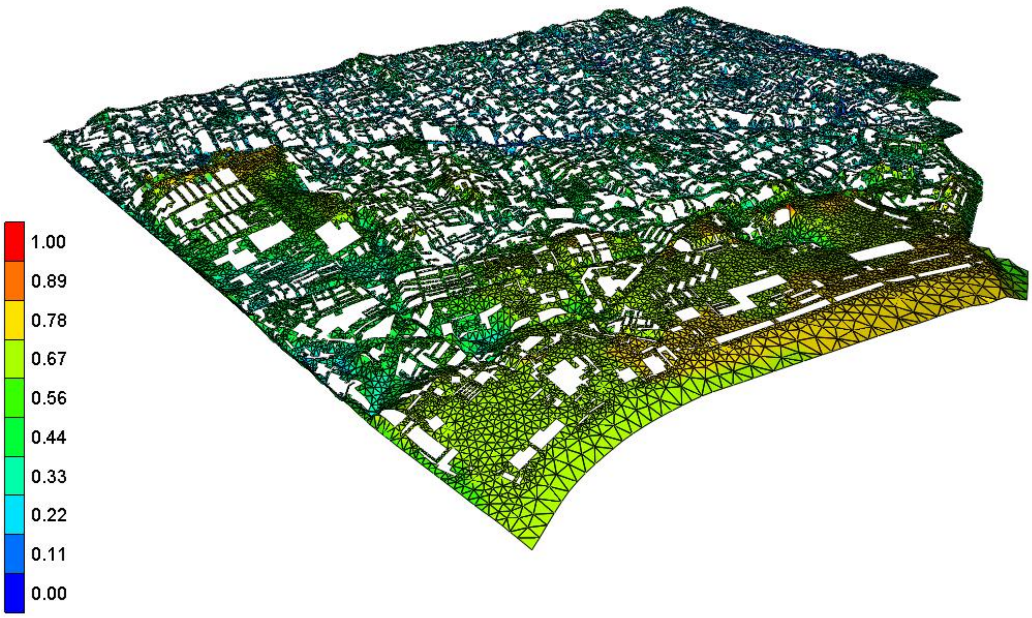


Figure 24 The updated 2D computational mesh for the Sukhumvit 1D/2D flood model. Note the “holes” representing the updated building shapes.

The updated mesh for the Sukhumvit 2D model has a total of 80 422 elements, with an average size of 184 $m^2$. The element size ranges from 5 to 4 600 $m^2$, with the smaller ones occurring over urban flow paths and between buildings, and the bigger ones in zones with flat, uniform terrain, including over hydrological features (i.e. river and *klongs* at the boundaries). In comparison, for a rigid grid 2D model with a resolution of 5 m, the total number of computation cells in the model area would be around 640 000.

## 2.2.3 Hydbrid/GPU Computing

Faster model simulations are also achieved by enabling simultaneous calculations on multiple processors (i.e. parallelisation), as well as use of different types of processing units to perform calculations. For the Sukhumvit flood forecasting system, instead of parallelisation employing just general-purpose CPU cores, the use of another type of processing unit (i.e. Graphics Processing Unit (GPU)) in conjunction with CPUs to perform computationally intensive calculations was applied.

This speed-up technique employing hybrid CPU/GPU computation was tested with the Sukhumvit 1D/2D flood model. It was then implemented in the system as tests showed that significant model speed-up (up to a factor of 4) could be achieved with a shift from rigid grid CPU computing, to flexible mesh hybrid GPU computing (see also Chapter 3).

# 3 Model Performance

The updated 1D network model was coupled to the modified 2D surface model to build the new integrated 1D/2D flood model for the area of Sukhumvit. In the process of updating the flood model, several iterations of its various components, especially the 2D computational mesh, were created and evaluated in terms of computational speed for forecasting purposes.

## 3.1 MIKE Flood Classic to MIKE Flood Flexible Mesh (FM)

The first set of tests evaluated the model speed-up gains with a shift from a rigid grid-based (MIKE Flood Classic) (DHI, 2015c) to flexible mesh-based (MIKE Flood FM) (DHI, 2015c) 1D/2D flood model, and the use of GPU computing (Table 4). Trying to make the test cases as consistent as possible, the rigid grid (used in Test 1 model) was directly converted into a mesh with quadrangular (i.e. square) elements (used in Tests 2 and 3 models).

Table 4 Tests of model performance with a shift from rigid grid- to flexible mesh-based flood models, and use of GPU computing.

| Test # | Model Type | Grid Size | # of Elements | Processor | Sim. Period [h] | Comp. Time [h] | Relative Time |
|---|---|---|---|---|---|---|---|
| 1 | MIKE Flood Classic (rigid grid) | 5 m | 639 815 | 2 CPU | 2.75 | 0.76 | 3.63 |
| 2 | MIKE Flood FM (quadrangular) | 25 $m^2$ | 639 815 | 2 CPU | 2.75 | 1.06 | 2.6 |
| 3 | MIKE Flood FM (quadrangular) | 25 $m^2$ | 639 815 | 1 GPU | 2.75 | 0.22 | **12.31** |

A mere change from a rigid grid to a flexible mesh model did not improve model performance, as the low number of CPUs in the computer being used limited parallelisation, which is a strong suit of the flexible mesh model. However, with GPU-computing, a speed-up factor gain of almost four times could be achieved (Table 4). This first set of tests illustrated the significant performance gains offered by hybrid GPU-computing. Results also serve as points in favour of the shift to a flexible mesh-based model, as GPU computing is only possible/implemented for this model type (i.e. MIKE 21 FM). In addition, the flexible mesh model offers the possibility of further refining and adjusting the number of computational elements, as well as sizes.

## 3.2 Number of Mesh Elements

Potential speed-up factor gain with a reduced number of computational elements was evaluated in the next set of tests (Table 5). As expected, the lower number of computational elements allowed faster computation times. In addition, the ability of GPU computing to significantly speed-up simulations was again observed. Comparison of model results after modification of the computational mesh (i.e. Test 2 and Tests 4 and 5) also show minimal differences despite the significant reduction in the number of elements (Figure 25).

Table 5 Tests of model performance with lowering the number of flexible mesh elements, and use of GPU computing.

| Test # | Model Type | # of Elements | Processor | Sim. Period [h] | Comp. Time [h] | Relative Time |
|---|---|---|---|---|---|---|
| 2 | MIKE Flood FM (quadrangular) | 639 815 | 2 CPU | 2.75 | 1.06 | 2.6 |
| 4 | MIKE Flood FM (triangular) | 237 588 | 2 CPU | 2.75 | 0.46 | 6 |
| 5 | MIKE Flood FM (triangular) | 237 588 | 1 GPU | 2.75 | 0.12 | **22.89** |

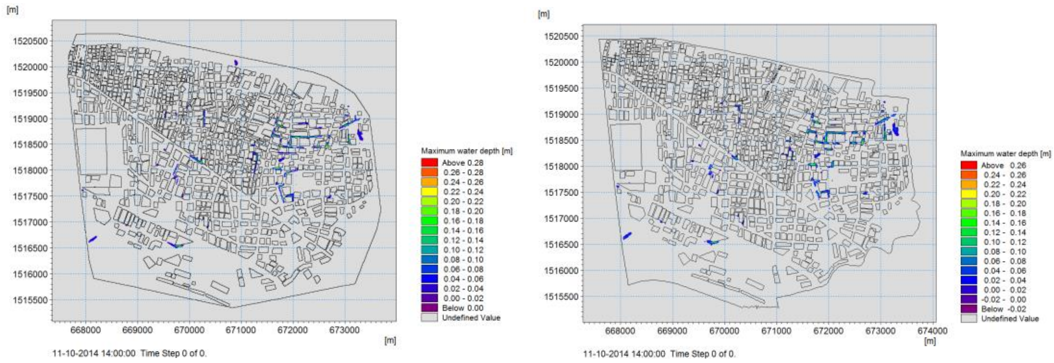


Figure 25 Comparison of simulated maximum flood depths and extents obtained from Test 2 (left), and Test 4 and 5 (right) setups.

## 3.3 Computational Time Step

With larger element sizes, computational time steps could also be increased to further speed up simulations. Tests with time step modification attained a 1.33 speed-up factor with the doubling of the maximum allowable time step for the Sukhumvit flood model (see Tests 6 and 7 in Table 6). This factor may seem modest compared to the increase in time step, but it should be noted that the time step specified in the MIKE 21 FM (DHI, 2015) setup is merely the maximum value that may be used during computations. Time steps are dynamically adjusted to satisfy CFL (Courant-Friedrichs-Lewy) conditions for numerical stability, and may still go well below the specified maximum value (e.g. when there are many wet elements). Comparison of model simulation results also shows very similar flood maps obtained from Tests 6 and 7 setups (Figure 26).

Table 6 Tests with MIKE Flood FM models run with GPU computing where time steps are increased.

| Test # | # of Elements | Max. Time Step [s] | Processor | Sim. Period [h] | Comp. Time [h] | Relative Time |
|---|---|---|---|---|---|---|
| 6 | 237588 | 1 | 1 GPU | 12 | 1.21 | 9.89 |
| 7 | 237 588 | 2 | 1 GPU | 12 | 0.91 | 13.16 |
| 8 | 117 642 | 2 | 1 GPU | 12 | 0.24 | **49.26** |

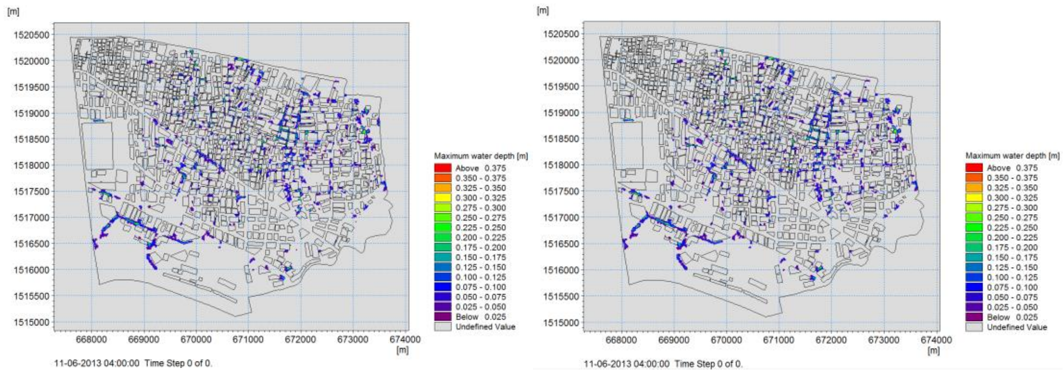


Figure 26 Comparison of simulated maximum flood depths and extents obtained from Test 6 (left), which uses a 1-s maximum time step, and Test 7 (right), uses a 2-s maximum time step.

In Test 8, the number of elements in the model was further reduced (by half) compared to the setups in Tests 6 and 7, and the maximum time step was kept at 2 s. With this configuration, a significant reduction in computation time was achieved, affording a speed-up factor of almost 5 between Test 6 and Test 8. Moreover, consistency in simulated maximum flood results was maintained (Figure 27).

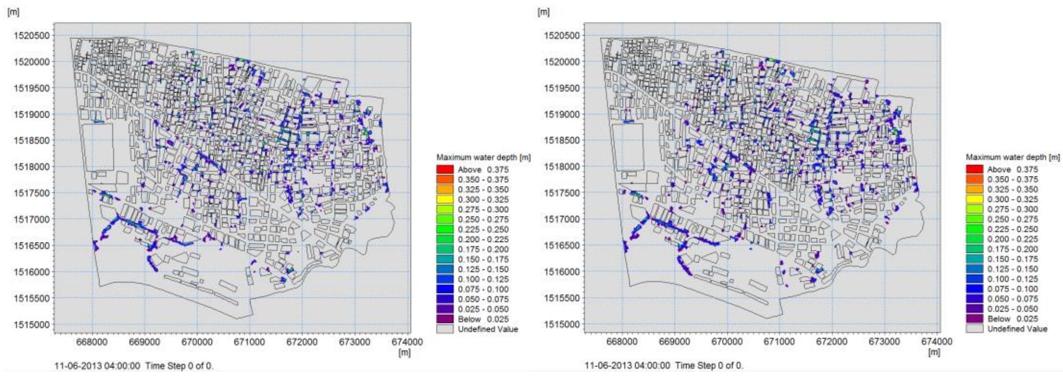


Figure 27 Comparison of simulated maximum flood depths and extents obtained from Test 7 (left), and Test 8 (right), which has half the number of mesh elements as the setup in Test 7 and uses a 2-s maximum time step.

## 3.4 Updated Sukhumvit Flood Model

A plot of the updated Sukhumvit flood model is shown in Figure 28. It is a coupled 1D/2D flood model, built in MIKE Flood Urban FM, linking:

- The updated 1D model of the sewer system. Some of the major changes to the model include removal of the redundant street network layer, pump data correction, and modification of outlet backflow/infiltration modelling (see Chapter 2.1)
- The modified 2D surface flow model for the area. The main changes to the model are the conversion of the old rigid (Cartesian) computational grid to a flexible mesh, and the use of updated GIS (i.e. buildings) data in mesh development (see Chapters 2.2.2 and 2.1.4).

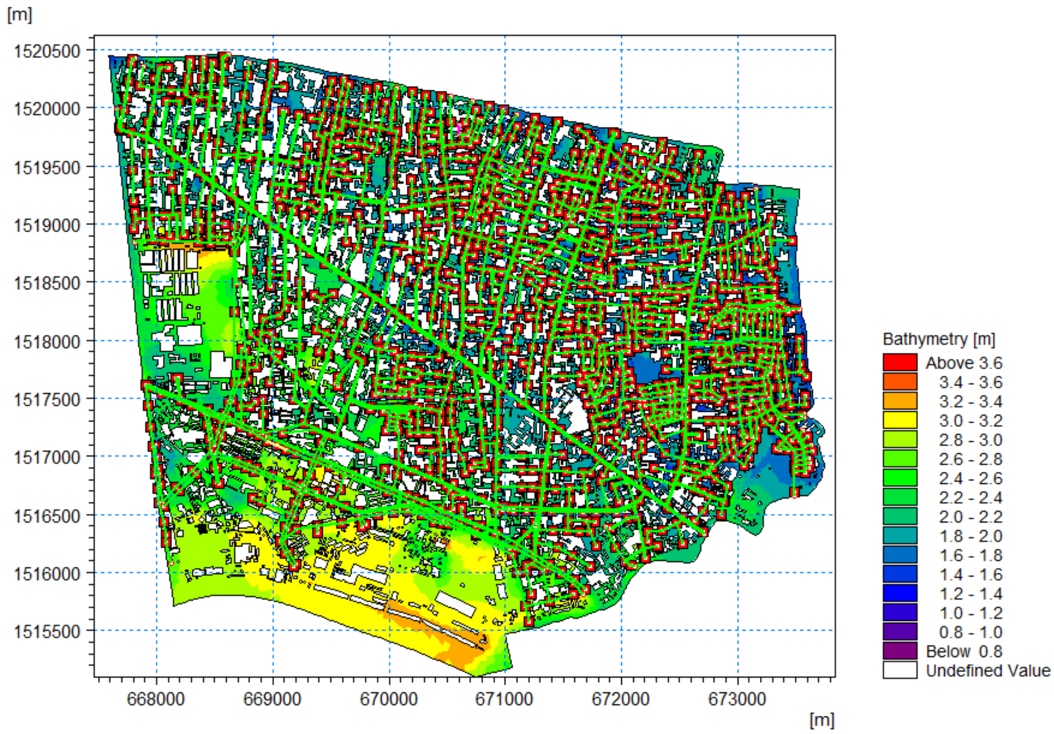


Figure 28 The updated Sukhumvit 1D/2D flood model showing the 1D-model network elements overlaying the 2D model mesh. Linking points between the two models are indicated by the red squares.

Two sets of model setups were built for the updated flood model:

1. Dry-weather model—wherein pump wet-well set points were those for Plan B conditions in the BMA data (BMA, 2017). (See also Chapter 2.1.5)
2. Wet-weather model—wherein pump wet-well set points were those for Plan A conditions in the BMA data (BMA, 2017) (See also Chapter 2.1.5). This setup was used for flood modelling, initiated (i.e. hot-started) with 1D network results from the dry-weather model.

### 25 October 2016 Flood Event

The updated Sukhumvit flood model was used to simulate a flood event from 25 October 2016 to evaluate its capacity to realistically model flooding in the area. Rainfall data for the event was obtained from BMA (Figure 29), and information on flood observations were also available.

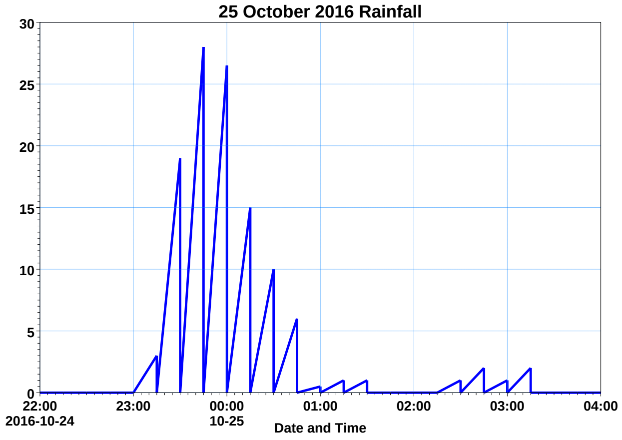


Figure 29 Rainfall data for the period 24 - 25 Oct. (04:00) showing 15-minute accumulated depths in mm.

Flood observations comprised of tabulated information on locations, and estimated depths and durations of flooding in the Sukhumvit area, as shown in Table 7 below.

Table 7 Data on the 25 October 2016 flood event in the Sukhumvit area obtained from BMA.

| RainStart | | RainStop | | Location | | Depth | Length | Duration |
|---|---|---|---|---|---|---|---|---|
| Date | Time | Date | Time | Road | From-To | cm | m | hr-min |
| 24-10-2016 | 22:00 | 25-10-2016 | 04:30 | Sukhumvit | Between Soi 25-71 (two sides) | 15 - 30 | | 03-45 |
| 24-10-2016 | 22:00 | 25-10-2016 | 04:30 | Rama 3 | Market Hong Kong - Penang | 15 - 20 | 300 | 02-10 |
| 24-10-2016 | 22:00 | 25-10-2016 | 04:30 | Sunthornkosa | Na Ranong intersection | 15 - 30 | 300 | 02-05 |
| 24-10-2016 | 22:00 | 25-10-2016 | 04:30 | Ekamai | throughout | 15 - 30 | 2500 | 03-00 |
| 24-10-2016 | 22:00 | 25-10-2016 | 04:30 | Asoke | throughout | 15 - 20 | 300 | 01-25 |
| 24-10-2016 | 22:00 | 25-10-2016 | 04:30 | Rama 4 | Railways - Sunthornkosa | 10 - 15 | | 02-35 |
| 24-10-2016 | 22:00 | 25-10-2016 | 04:30 | Rama 4 | Kasemrad junction to Kluaynamthai | 10 - 15 | | 02-35 |
| 24-10-2016 | 22:00 | 25-10-2016 | 04:30 | Kasemrad | Port - Rama 4 | 10 - 15 | 1000 | 02-25 |
| 24-10-2016 | 22:00 | 25-10-2016 | 04:30 | Rama 4 | Toei market | 15 - 20 | | 02-35 |

Model simulation results show widespread flooding in the area during the 25 October 2016 event (Figure 30). Flooding was also simulated in the areas reported to be flooded according to records (Table 7 and Figure 30). An average maximum depth of 18 cm and an average flood duration (above a 10-cm threshold) of 2 hours were simulated for the selected event.

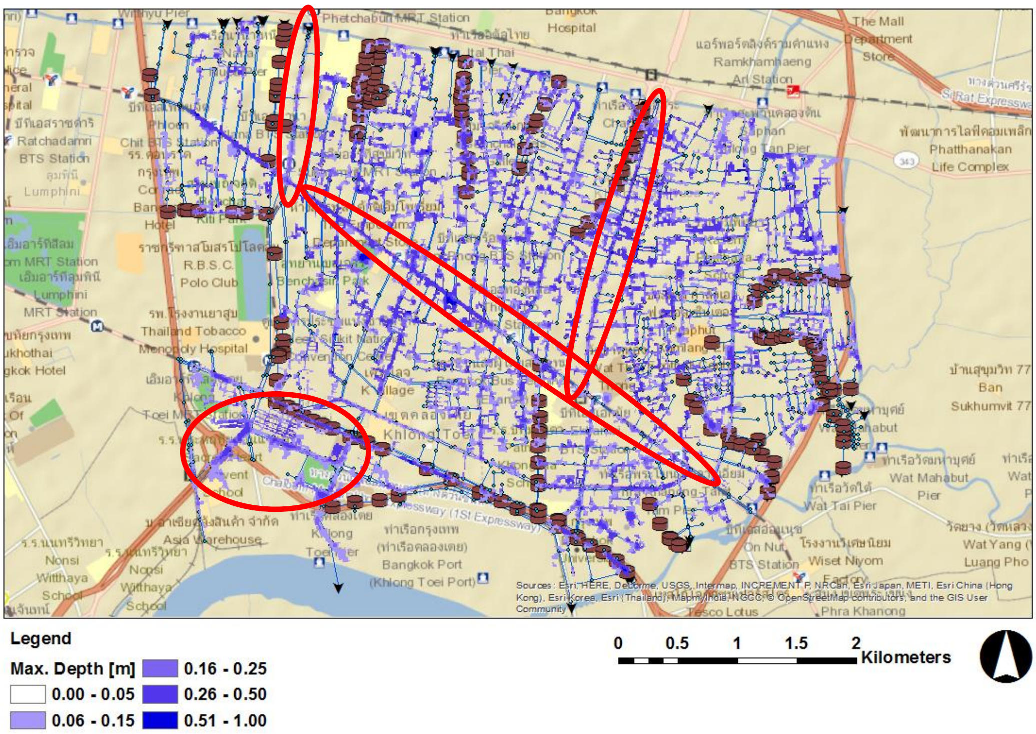


Figure 30 Plot of simulated maximum flood depths [m] for the simulation period 24 Oct. (22:00) – 25 Oct. (04:00) in Sukhumvit. Encircled areas are those reported in Table 7.

# 4 Summary

The 1D/2D urban flood model for the Sukhumvit area in Bangkok was updated to adapt it to real-time flood forecasting system use. From various checks and updating, and based on performance tests conducted, the Sukhumvit 1D/2D flood model (see Figure 28) update involved:

- Reconfiguring the 1D network model for appropriate use in a coupled 1D/2D modelling method (i.e. MIKE Flood)
- Reflecting updated pump data from BMA in the 1D model
- Using new GIS and DTM data from BMA
- Shifting the 2D computational mesh type from rigid grid (i.e. MIKE 21 Classic) to flexible mesh (i.e. MIKE 21 FM)
- Using a mesh with around 80 000 elements, instead of the original 600 000 cells in the previous computational grid
- Operationally running the model using GPU-computing to achieve relative computation times (i.e. simulation/computation time) of around 28 (i.e. 28 times faster than real life)

The updated 1D/2D flood model of Sukhumvit reflects the best available recent data on the drainage system and area characteristics in the study area. It is an integrated 1D/2D flood model build with MIKE Flood FM, dynamically simulating overland surface flows (with MIKE 21 FM), as well as subsurface drainage network flows (with MIKE Urban). The model, especially the 2D component, had been optimised for application in flood real-time forecasting.

Simulation of a flood event from 25 October 2016 indicate that the updated model can realistically model flooding in the Sukhumvit area, as flood occurrence and depths at the points of observed flooding could be simulated. Nevertheless, further verification of the model is needed against other flood event data, as currently, overestimation of flood extents is possible as illustrated by the widespread flooding simulated with the model.

During the model update, it was apparent that pumps are the main modes of evacuating water from the study area, as the terrain is very flat and low-lying. It is crucial that accurate and comprehensive pump data—on capacities and, most especially, operation—could be used in developing the sewer network model to ensure that realistic pump operation could be modelled. Modelling the pump stations in the flood model could be further improved, especially with respect to representing the operational rules currently in place, as data on these operational rules were largely unavailable and had to be assumed in the project.

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